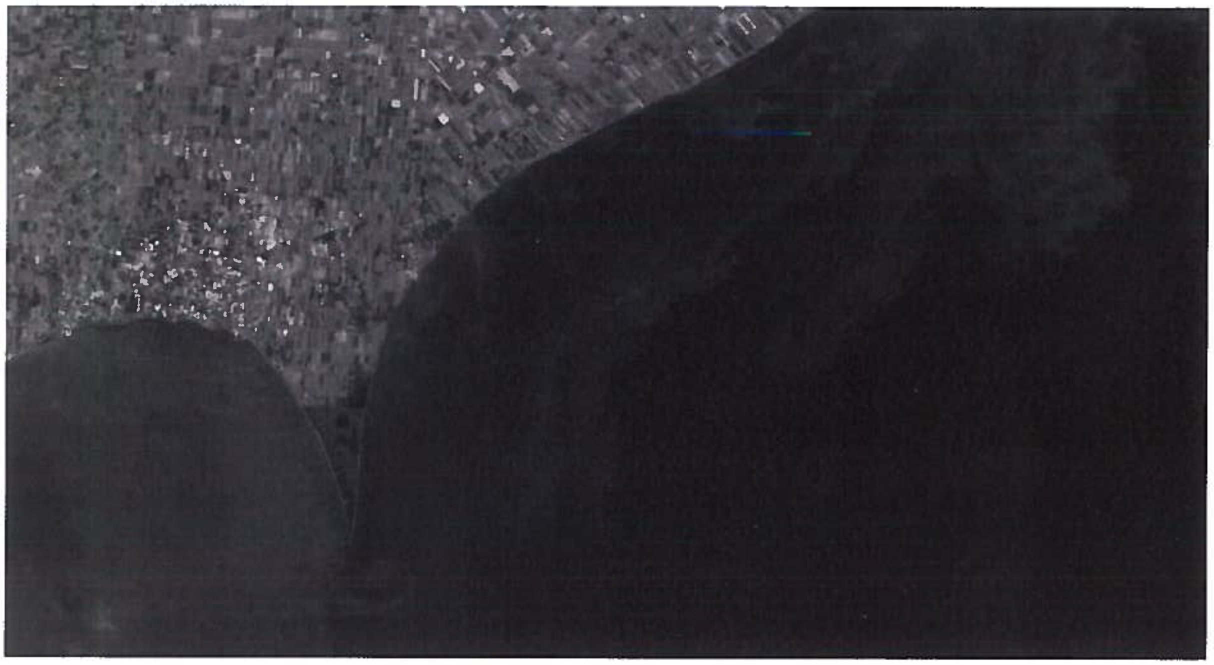

Cyanotoxins in US Drinking Water: Occurrence, Case Studies and State Approaches to Regulation

September 2016

American Water Works Association

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The American Water Works Association is the largest nonprofit, scientific and educational association dedicated to managing and treating water, the world's most important resource. With approximately 50,000 members, AWWA provides solutions to improve public health, protect the environment, strengthen the economy and enhance our quality of life.

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Executive Summary

Cyanotoxins have long been recognized as potential sources of contamination for drinking water supplies. Despite this, cyanotoxins are not regulated under the Safe Drinking Water Act (SDWA). However, there are indications that cyanotoxins may be regulated under the SDWA in the future.

In August 2014, the City of Toledo, Ohio issued a Do Not Drink/Do Not Boil (DND/DNB) order because of detections of the cyanotoxin microcystin in their finished water. Nearly 500,000 people were impacted during the weekend-long DND/DNB order, which was the largest cyanotoxin-related DND/DNB order in United States history. This event has put renewed emphasis on cyanotoxins in drinking water, and resulted in Congress directing the United Sates Environmental Protection Agency (USEPA) to prepare a strategic plan for algal toxin risk assessment and management in drinking water. Related to these efforts, USEPA has issued Health Advisories (HAs) for two cyanotoxins: microcystins and cylindrospermopsin. These HAs are not Federal standards nor are they legally enforceable; instead, they are intended to provide public health officials with information regarding the concentration of a contaminant in drinking water at which adverse health effects are not anticipated. In addition to issuing the HAs for microcystins and cylindrospermopsin, USEPA has also proposed adding several cyanotoxins (microcystins, nodularin, anatoxin-a, and cylindrospermopsin) to the compounds included in the next round of Unregulated Contaminant Monitoring Rule (UCMR 4) monitoring.

Since cyanotoxins are not regulated, there was little data available prior to the 2015 bloom season regarding the ability of public water systems (PWSs) to meet the HA levels for microcystins and cylindrospermopsin issued by USEPA. There were several unknowns going into the 2015 bloom season: 1) how many PWSs would have source waters contaminated with cyanotoxins, and to what extent; 2) would any cyanotoxin-related DND/DNB orders be issued, and what would the impact of such orders be; and 3) how would PWSs adjust treatment to remove cyanotoxins and what would the impact of those modifications be? Recognizing these unknowns, the American Water Works Association's (AWWA) Government Affairs Office initiated a study through the Water Industry Technical Action Fund (WITAF) to develop a spreadsheet of cyanotoxin occurrence in source and treated drinking water and to catalogue the impact of USEPA's HAs on PWSs.

As part of that effort, the project team identified data sources for cyanotoxin concentration, collected available data and analyzed those data. This report provides: background information describing the guidance in place for cyanotoxins in drinking water, data sources used for collecting cyanotoxin occurrence and concentration data, currently available data, case studies about utilities that have been treating water containing cyanotoxins and recommendations for future data collection and analysis efforts.

Most of the state primacy agencies that responded for this study do not plan to take action on the USEPA HAs on microcystins and cylindrospermopsin because it is not regulation. Some state representatives cited legal concerns over enforcing a standard that is not in regulation. Only

Ohio, Maryland, Rhode Island and South Carolina definitively intend to take action when sample results indicate levels over the HA. However, many of the PWSs contacted were aware of the potential for cyanotoxin contamination and were targeting finished water cyanotoxin concentrations below the HA limits.

Determining the occurrence of cyanotoxins across the United States is difficult due to the lack of data collection and reporting in many states. However, prior studies indicate that cyanotoxins may be widespread. Previously the United State Geological Survey (USGS), in conjunction with the USEPA National Lake Assessment, determined that microcystin was present in 33 percent of samples collected from 1,028 lakes, reservoirs and ponds in 2007. Cylindrospermopsins and saxitoxins were less prevalent, with detections in 5 and 8 percent of the samples respectively. Geographical trends were apparent in the occurrence data. Microcystin detections were common in the Midwest, while saxitoxins occurred most in the upper Midwest and south. Texas, Florida and the Ohio, Indiana and Kentucky region had the most cylindrospermopsin detections (Graham and Loftin 2014). No treated drinking water samples were collected in this study.

More recent cyanotoxin occurrence data do not capture the full extent of cyanotoxin occurrence in the United States for several reasons. First, the majority of states do not require cyanotoxin monitoring in drinking water. In states with testing programs, the monitoring data are not in a consistent format from state to state. Since there is no USEPA requirement for testing, various analytical methods are used and often the method used is not indicated when data are reported. Despite these limitations, there is value in examining the available data to determine the current state of knowledge and the most beneficial next research steps.

Recreational water use and drinking water cyanotoxin data from six states were incorporated into an occurrence spreadsheet. The majority of the data are from Ohio. Detections of microcystin are possible year-round, however, there is a seasonal trend to the data with the highest concentrations occurring in the late summer and early fall.

All of the treated water cyanotoxin detections were from Ohio. Treated drinking water samples were generally collected on the same day as the source water samples (throughout this report, "source water" refers to water collected at or shortly prior to entry into a water treatment facility, which will be treated to become drinking water). Although 43.9 percent of source water drinking water samples in Ohio exceeded the microcystin USEPA Health Advisory of 0.3 µg/L, 1.16 percent of treated drinking water samples exceeded that same threshold. This demonstrates the ability of the treatment processes in place at the Ohio plants to reduce microcystin levels in drinking water while maintaining other treatment priorities with the circumstances seen during the monitoring period. The 2014 Toledo event included 15 treated water detections that occurred between August 1st and August 19th. This accounts for 57 percent of the detections above 0.3 µg/L in treated drinking water among all Ohio samples. Under the current health advisory framework Toledo would have likely had to issue a second DND/DNB in mid-August 2014, in addition to the notice that was in effect August 2nd through the 4th. There were no other locations where a DND/DNB would have been considered.

Utilities with cyanotoxin detections in their surface water sources were contacted in an effort to understand how PWSs respond during a cyanotoxin-producing algal bloom event. Sixteen PWSs agreed to be interviewed and provide information, including twelve in Ohio, two in Oregon, and PWSs in Kentucky and Texas. Interview questions focused on: 1) how the PWS detected the presence of cyanotoxins and what toxins were detected, 2) how did the PWS modify operations and treatment to limit the impact from the cyanotoxins, and 3) what were the impacts to the utility (financial, public relations, etc.) from the cyanotoxin-producing algal bloom event?

All of the PWSs that were interviewed detected cyanotoxins in their source water, and all were able to adequately remove the influent toxins so as to avoid DND/DNB orders. Standard operating procedures (SOPs) for monitoring and responding to cyanotoxin-producing algal bloom events varied between PWSs. Microcystin was the only cyanotoxin detected in Ohio, while cylindrospermopsin was detected in both Texas and Oregon. Anatoxin-a was also detected in Oregon. PWSs in Ohio predominantly used the (all-*S*, all-*E*)-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid (ADDA)-based enzyme-linked immunosorbent assay (ELISA) laboratory method, while the PWSs in other states relied on liquid chromatography tandem mass spectrometry methods (LC/MS/MS).

Three of the PWSs that were interviewed were able to adequately treat the influent cyanotoxins without modifying plant operations. Two of these three included biologically active treatment components (slow sand filters or granular activated carbon (GAC) filter caps that are biologically active), while the third plant sees cyanotoxins throughout the year and treats using a combination of ozone and GAC contactors. The other 13 PWSs that were interviewed modified operations to increase cyanotoxin removal. The process modifications included the addition of powdered activated carbon (PAC), increase in disinfection oxidant dosages, and changes to pre-filtration oxidant dosages. Only one system reported detection of microcystin in their finished water, which was not confirmed by follow up sampling. In all, the process modifications performed by the PWSs proved effective in removing cyanotoxins, although in some instances this raised challenges with other treatment needs such as disinfection byproducts (DBPs).

It proved difficult for most PWSs to assess the impact that responding to the cyanotoxin-producing bloom event had on their plants. While all of the interviewed utilities were impacted in some way by the presence of cyanotoxins in their surface water sources, financial costs incurred primarily related to additional chemical usage. Other cost factors, such as operator overtime, additional monitoring and analysis costs, etc. were generally not available.

Following data collection and review, the project team identified a 2016 DND/DNB order due to microcystin contamination issued by the City of Ingleside, Texas. A sample of discolored water collected by one of their customers from their in-home plumbing was identified as containing microcystins. Subsequent sampling identified a localized concentration of microcystins in an area of the City's distribution system, but not in the wholesale water provider's system. This, together with identification of unprotected cross-connections, indicates the microcystins were introduced via a cross-contamination event. Following detection, the City issued a DND/DNB order for all customers in the affected area of the distribution system and implemented flushing and installed new reduced pressure zone backflow preventers to attempt to alleviate the problem. Four days after the initial DND/DNB order was issued, microcystin concentrations had reduced substantially but spread further throughout the distribution system. This led the City to lift the initial DND/DNB order, but to issue a citywide DND order for children under the age of 6 and immunocompromised individuals. Thirteen days after the initial DND/DNB order, the City lifted the citywide DND order after three consecutive rounds of sampling failed to detect microcystins.

Recommendations

In retrospect, the 2015 bloom season was handled remarkably well by PWSs in the United States. No DND/DNB orders were issued in 2015, despite favorable conditions towards cyanotoxin formation in much of the country and two extremely large blooms in Lake Erie and the Ohio River that impacted utilities in multiple states.

After reviewing the data that was compiled and speaking to utilities, a few trends are apparent that should be investigated further:

1. In many instances, detections of cyanotoxins in the finished water are not replicated in follow up sampling. It is not clear from the data if these detections represent false positives, actual detections that are not repeated due to changes in plant operation, or some other phenomena. It would be useful to investigate why there are so many "single data point" detections reported in finished water.

2. The utilities that were interviewed for this project generally had not fully quantified the cost of responding to the cyanotoxin-producing algal bloom. Most of the utilities could document the cost of additional treatment chemical (PAC, coagulant, pre-oxidant, etc.) that was used during the bloom, but none of the utilities fully captured other costs incurred such as staff overtime, additional monitoring and analysis, etc. Better methods of capturing costs are needed to document the impact that responding to cyanotoxin-producing bloom events has on the industry.

3. By far, the majority of the analyses for cyanotoxins during the 2015 bloom season were for microcystins. It is not clear if this fully captures the risk of cyanotoxin contamination, or if it is appropriate for most utilities to increase monitoring beyond microcystins to include other cyanotoxins including β-N-methylamino-L-alanine (BMAA) and 2,4-diaminobutyric acid dihydrochloride (DABA).

4. Analytical methods and sampling methodologies were not uniform amongst the states. For example, the minimum detection limit for microcystins varied between 0.01 to 0.6 µg/L, making comparability across data sets difficult. In some instances, the analytical methods used were not listed. This posed challenges in analysis and could prove challenging for utilities seeking to monitor their source and/or finished water, and increased standardization and validation of methods and sampling techniques is warranted.

INTRODUCTION

Cyanotoxins, a broad group of phycotoxins produced by cyanobacteria, have long been recognized as potential sources of contamination for drinking water supplies. As far back as 1930, there have been suspected links between algal blooms in municipal water supply source waters and gastroenteritis outbreaks (Dillenberg and Dehnel 1960). These blooms contained both *Microcystis* and *Anabena* species, both of which are genera in the cyanobacteria phylum. Although cyanobacteria are prokaryotes and are generally considered distinct from algae, which in modern taxonomy is reserved for eukaryotes, in the literature and in practice cyanobacterial blooms are commonly referred to as algal blooms.

Algal blooms can contribute to a number of potential issues in surface water treatment plants including release of taste- and odor-causing compounds, filter clogging, and depletion of dissolved oxygen in reservoirs (Yoo, et al. 1995). In addition to these issues cyanobacteria can also release a range of compounds, referred to collectively as cyanotoxins, that act as either neurotoxins, hepatoxins, or contact irritant-dermal toxins (Carmichael 2001). The toxins produced by a specific bloom depend on the type and species of cyanotoxins present. This project focused specifically on the toxicological aspect of cyanobacterial blooms, and did not include consideration of aesthetic or operational challenges that may also occur during an algal bloom event.

Although the industry was aware of the potential for toxins to be released during algal bloom events, it wasn't until the 1970s that researchers began investigating the potential for drinking water treatment processes to treat for cyanotoxins (Hoffman 1976). In 1996 the potential risk of algal toxins in municipal drinking water supplies was unfortunately realized when 50 hemodialysis patients in Brazil died from liver failure resulting from exposure to the cyanotoxin microcystin[1] in the water used for dialysis (Jochimsen, et al. 1998). Despite these risks, however, cyanotoxins have not historically been regulated in the United States. Although cyanobacteria and their toxins have been identified as microbial contaminant candidates on every Drinking Water Contaminant Candidate List (CCL) that the United States Environmental Protection Agency (USEPA) has issued under the Safe Drinking Water Act (SDWA) to date, cyanotoxins have not been included in any of the three Unregulated Contaminant Monitoring Rules (UCMRs) that resulted from the CCL development, although 10 cyanotoxins have been identified for inclusion on the next round of UCMR testing (UCMR4) which is scheduled to begin sampling in 2018. Beyond this UCMR4 sampling, there are not currently any regulations under SDWA that deal with cyanotoxins in drinking water. This certainly could change in the future.

In August 2014, the City of Toledo, Ohio issued a Do Not Drink/Do Not Boil (DND/DNB) notice to all customers served by their water system because of a detection of microcystin in their treated water that exceeded the lifetime chronic exposure threshold concentration of 1 µg/L established by the Ohio Environmental Protection Agency (OEPA) at that time. This weekend-long DND/DNB

[1] Microcystin is thought to be the most commonly occurring toxin in a class of toxins termed cyanotoxins. Cyanotoxins are potent toxins produced by some species of cyanobacteria.

impacted nearly 500,000 residents and businesses served by the City of Toledo, and was the largest DND/DNB order caused by cyanotoxin contamination in United States history. This event was quickly followed by regulatory efforts to manage the risk of algal toxins in drinking water. On January 8, 2015 a bill known as the "Drinking Water Protection Act" was introduced into US House of Representatives to amend SDWA to require USEPA to develop a strategic plan for assessing and managing risks associated with algal toxins in drinking water provided by public water systems (H.R. 212). Although this bill did not specify or require regulatory limits for cyanotoxins, it emphasized the need for a plan to manage cyanotoxins at the federal level.

In the summer of 2015, prior to ratification of H.R. 212, USEPA issued health advisories (HAs) for two specific cyanotoxins: microcystins and cylindrospermopsin. Health advisories are intended to provide information for public health officials on pollutants that are not regulated under the Safe Drinking Water Act but are capable of affecting drinking water quality. HAs do not establish regulatory limits, but instead identify the concentration of a contaminant in drinking water at which adverse health effects are not anticipated to occur over specific exposure durations. USEPA also developed a Health Effects Support Document for the antitoxin-a, but concluded that available toxicity data were inadequate for deriving a health-based value for that cyanotoxin (USEPA 2015a).

For both microcystins and cylindrospermopsin, USEPA established two ten-day HA levels based on age ranges: a lower HA value was established for bottle-fed infants and young children of pre-school age, while a higher HA value was established for school age children and adults (USEPA 2015b, USEPA 2015c). The microcystin and cylindrospermopsin HA levels for children under the age of 6 were set at 0.3 µg/L and 1.6 µg/L respectively. For children over the age of 6 and adults, the HA level was set at 1.6 µg/L for microcystins and 3.0 µg/L for cylindrospermopsin.

In response to the Drinking Water Protection Act, USEPA released an Algal Toxin Risk Assessment and Management Strategic Plan for Drinking Water in late 2015 (USEPA 2015d). This strategic plan describes a number of current and future initiatives that USEPA is pursuing or plans to pursue to understand and manage risk from cyanotoxin-producing algal blooms. Perhaps most importantly from a regulatory perspective is the inclusion of microcystin-LR, cylindrospermopsin, and anatoxin-a as priority contaminants in the fourth CCL (currently in draft), and the publication of two liquid chromatography tandem mass spectrometry (LC/MS/MS) methods for cyanotoxin analysis (USEPA 2015e, USEPA 2015f). Cyanotoxins were not included in the first three UCMRs because cyanotoxin analytical methods were insufficient (USEPA 2015d)); with the development of the new analytical methods and the identification of cyanotoxins as priority contaminants in the draft CCL 4, it appears likely that cyanotoxins will be included in UCMR 4, which could eventually lead to development of MCLs for microcystins, cylindrospermopsin, and/or anatoxin-a.

Based on the above considerations, and recognizing the scarcity of currently existing data regarding how frequently public water systems (PWSs) experience cyanotoxin contamination in their source water and what the impact of such contamination might be, AWWA initiated this study to investigate the observed levels and associated impacts of cyanotoxins on PWSs during the 2015 cyanotoxin-producing bloom season. The purpose of the study is to provide hard data to support development of state guidance and to set the stage for future data collection efforts. To achieve that purpose the project team identified data sources for cyanotoxin concentration, collected available data and analyzed those data. This report provides: background information describing the guidance currently in place for cyanotoxins in drinking water, the data sources used for collecting cyanotoxin occurrence data, currently available data, case studies about utilities that have been treating water containing cyanotoxins and recommendations for future data collection and analysis efforts.

GLOBAL APPROACH TO CYANOTOXINS IN DRINKING WATER

The most common bloom-forming genus of cyanobacteria is *Microcystis*, which produces toxic microcystins (Yoo, et al. 1995). There are approximately 100 known congeners of microcystin (congeners are compounds that are related to each other by origin, structure, or function). Of these, the most common and the most studied congener is microcystin-LR, which contains and is named for the amino acids leucine (L) and arginine (R). In much of the literature and guidance documentation, microcystin-LR is used as a surrogate for all other microcystin congeners.

The World Health Organization (WHO) derived a guidance for microcystin-LR as follows (WHO 1998):

> *A 13-week study in mice with microcystin-LR (Fawell, James, and James 1994) is considered the most suitable for the derivation of a guideline value. In this study, a NOAEL of 40 µg/kg of body weight per day was determined for liver pathology. A TDI of 0.04 µg/kg of body weight per day can be calculated by applying an uncertainty factor of 1000 (100 for intra- and interspecies variation, 10 for limitations in the database, in particular lack of data on chronic toxicity and carcinogenicity) to the NOAEL. An allocation factor of 0.80 is used for the proportion of daily exposure arising from drinking-water, because there is little exposure from any other source and route. The resulting guideline value for total microcystin-LR (free plus cell-bound) is 1 µg/litre (rounded figure) in drinking-water.*

The WHO did not develop guidance for any other congeners because there were insufficient health effects data.

In fourteen of the sixteen countries with microcystin guidance or regulation, the WHO guidance level of 1 µg/L is utilized (USEPA 2015b, Chorus 2013). Canada and Australia established slightly different levels using the same underlying Tolerable Daily Intake (TDI) value, but different factors in the calculation of the advisory level (Government of Canada, Health Canada and the Public Health Agency of Canada 2002, Austrailian Government 2011). A summary of international guidance and regulation for a variety of cyanotoxins is shown in Table 1.

Table 1. International cyanotoxin guidance and regulation summary

	Microcystin[1] (µg/L)	Cylindrospermopsin (µg/L)	Anatoxin-a (µg/L)	Nodularin (µg/L)	Saxitoxin (µg/L)
Range	1 – 1.5	1 - 15	1 - 6	1	3
Number of countries with regulation or guidance [3]	16	2	2[2]	1	3

[1] Some of the guidance and regulation is for microcystin-LR, and others are for all microcystins. Countries include Australia, Brazil, Canada, Czech Republic, Denmark, France, Finland, Germany, Italy, Netherlands, New Zealand, Singapore, Spain, Turkey, Uruguay and South Africa.
[2] The Providence of Quebec, Canada limit is included, although it does not apply to all of Canada
[3] Excluding the US

Cylindrospermopsin, anatoxin-a, nodularin and saxitoxin have guidance or regulation in a handful of countries, but similar to the U.S., the international focus has been on microcystins.

UNITED STATES APPROACH TO CYANOTOXINS IN DRINKING WATER

As discussed previously, cyanotoxins are not currently regulated at the federal level. However, state primacy agencies are free to issue their own guidance or regulations for cyanotoxins in drinking water. To date, three states have proactively issued guidance or regulation for cyanotoxins in drinking water. These values are summarized in Table 2 (Minnesota Department of Health 2015, USEPA 2015b, Oregon Health Authority 2012).

Table 2. States guidance for cyanotoxins summary

State	Microcystins (µg/L)	Cylindrospermopsin (µg/L)	Anatoxin-a (µg/L)	Saxitoxin (µg/L)
Minnesota	0.1 [1]	NG[2]	NG	NG
Ohio [3]	0.3	0.7	20	0.2
Ohio [4]	1.6	3.0	20	0.2
Oregon [3, 5]	0.3	0.7	0.7	0.3
Oregon [4]	1.6	3	3	1.6

[1] Microcystin –LR
[2] No guidance
[3] Children under 6 and sensitive populations
[4] Children 6 and older and adults
[5] Oregon previously used WHO recommended levels for Microcystins, switching to USEPA levels due to HAs

Ohio and Oregon have guidance values for anatoxin-a, saxitoxin, and cylindrospermopsin in addition to microcystins. In Table 2, Ohio values have been separated onto two lines to reflect that OEPA has established different guidance values for children and sensitive populations for microcystins. These values are consistent with the HA issued by USEPA in 2015. The Minnesota and Ohio values were modified in 2015 (OEPA 2014, USEPA 2015b, Minnesota Department of Health 2015). Previously Ohio had a microcystin guideline of 1 µg/L and Minnesota had a guideline of 0.04 µg/L for Microcystin-LR only.

States are taking a variety of approaches for responding to the HA. As part of this project, state primacy agencies were contacted to determine how they were approaching the issue of cyanotoxins in drinking water. This data was collected independently from the Association of State Drinking Water Administrators (ASDWA) survey of states. A detailed spreadsheet summarizing the various states approaches can be found in Appendix A. A simplified version of the information is presented in Table 3, however many of the states have subtle clarifications on one or more topics. No algal toxin expert was reached in 14 states. There were 5 states that were currently reviewing or developing their approach to addressing cyanotoxins in drinking water when this report was compiled.

Table 3. State approaches to USEPA Health Advisories

States	Action on HA?	Monitoring required?	Intend to collect data?	Written guidance complete, or in development?
OH, RI	Yes	Yes	Yes	Yes
MD	Yes	No	Yes	Yes
AL, CO, CT, IL, KS, MA, ME, NH, OR, VT	No	No	Yes	Yes
SC	Yes	No	Yes	No
CA, WI	No	No	No	Yes
AR, IA, UT	No	No	Yes	No
AK, AZ, DE, FL, HI, MN, MT, NC, NM, NV, OK, PA	No	No	No	No
GA, ID, IN, KY, LA, MI, MS, NE, ND, SD, TN, VA, WA, WV	No algal toxin expert was reached.			
MO, NJ, NY, TX, WY	Currently reviewing or developing their approach to addressing cyanotoxins in drinking water.			

Most states that responded do not plan to take action on the HA because the USEPA advisories are not regulations. Some state representatives cited legal concerns over enforcing a standard that is not in regulation. Ohio is taking the most proactive steps. Most states are not tracking this issue very closely.

OCCURRENCE BACKGROUND

Trends in Cyanotoxin Occurrence

In general, there appears to be an intensification in occurrence of cyanotoxin-producing algal blooms worldwide (de Figueiredo, et al. 2004). While there is still much that is unknown regarding cyanobacteria ecology, an increase in cyanotoxin-producing algal blooms in the past has been linked to two major factors. The first is the eutrophication of freshwater sources caused by nutrients, primarily nitrogen and phosphorus (Dolman, et al. 2012, Yuan, et al. 2014). The other is the impact of climate change that is producing a warming trend in the majority of lakes (O'Reilly, et al. 2015). Warming trends may lead to increases in Harmful Algal Blooms (HABs) that, in turn, have a significant impact on monitoring and management of bloom events (Paerl and Paul 2012, Backer and Moore 2010, Delpla, et al. 2009).

Global Overview

In many countries, cyanotoxins have been viewed primarily as a recreational water issue. However, there is a growing awareness of the public health risk cyanotoxins pose in drinking water and thus the need to monitor and remove cyanotoxins in the drinking water treatment process. Many studies report only low (below WHO or local guidelines) or undetectable levels of cyanotoxins in treated drinking water even when cyanotoxins are present in the source water (Chorus 2013, Rapala, et al. 2006, Szlag, et al. 2015, Bogialli, et al. 2012, Hoeger, Hitzfeld and Dietrich 2005, Hoeger, Shaw, et al. 2004).

Not all studies on cyanotoxins in drinking water indicate that adequate barriers are in place. In 1996, in Brazil, inadequately treated surface water was linked to the deaths of 52 dialysis patients after microcystins present in finished drinking water also passed through on-site pretreatment consisting of sand filtration, carbon adsorption, deionization, and micropore filtration (Carmichael, Health Effects of Toxin-Producing Cyanobacteria: "The CyanoHABs" 2001, Jochimsen, et al. 1998). Another study of a conventional drinking water treatment plant on the Nile river in Egypt reported microcystin reaching concentrations as high as 3.6 µg/L in the treated water (Mohamed, et al. 2015). The cyanobacterial biovolume was dense in the source water ($1.1–6.6 \times 10^7$ cells/L). It is important to remember that much of the developing world does not have as strong of management practices and regulations as the U.S.

Historical Occurrence Data in the US

The USGS, in conjunction with the USEPA National Lake Assessment, determined microcystins, cylindrospermopsin, and saxitoxin concentration in samples from 1,028 lakes, reservoirs and ponds in 2007 (Graham, Loftin and Meyer, et al. 2010, Graham, Loftin and Kamman 2009, Loftin 2008). There were 5 microcystin congeners analyzed: LA, LR, LY, RR and YR (Loftin, Graham, et al. 2016). Figure 1 shows a map of the continental US with the microcystin concentrations over 0.3 µg/L that were found during the 2007 National Lake Assessment survey.